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## PART 1

### INTRODUCTION

#### Chapter 5. PCBs in the Lake Michigan Ecosystem

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##### 1.5.1 Introduction

Within this chapter, polychlorinated biphenyl (PCB) data for Lake Michigan are summarized. These data are then compared to historical data. Summaries of the 1994-1995 data are taken directly from the “Results of the Lake Michigan Mass Balance Study: Polychlorinated Biphenyls and *trans*-Nonachlor Data Report” (McCarty *et al.*, 2004) and are referenced appropriately. Presentation of the data are arranged by media.

Details of the use of PCBs within the Lake Michigan basin are difficult to document. However, a list of significant dates for the basin was compiled from a variety of online sources. PCBs appear to have been first purchased for use in the basin in 1948 (Table 1.5.1). Use appears to have been phased out by 1972. Remediation of PCBs at various locations began in the late 1980s with Sheboygan Harbor

being the earliest completed in 1991. Remediation continues to this day.

##### 1.5.2 Atmospheric

Atmospheric concentrations measured include vapor phase, precipitation, particulate, and dry deposition PCBs. Each of these is plotted for stations within the basin that are representative of the annual seasons for 1994 and 1995.

###### 1.5.2.1 Vapor Phase

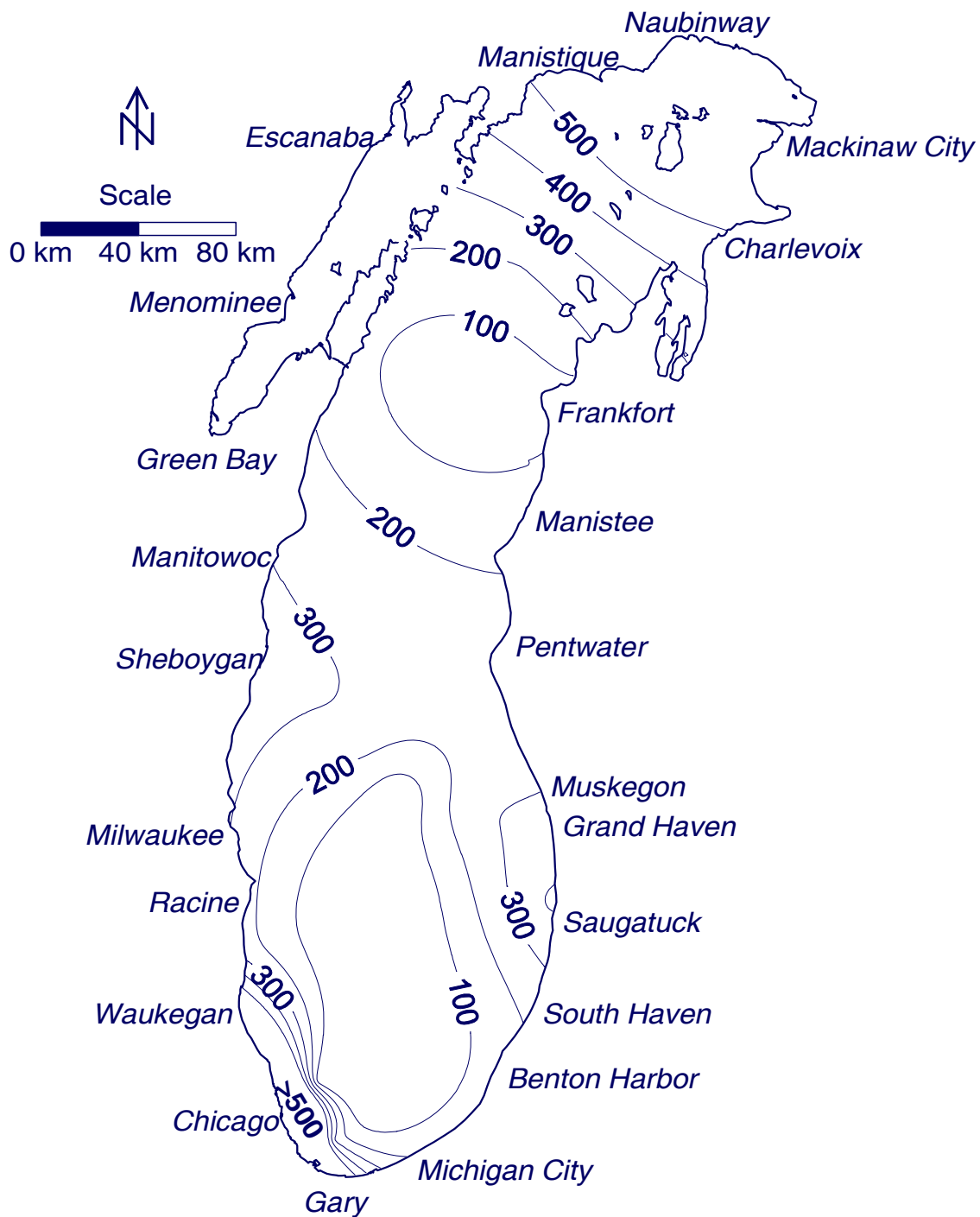
Median vapor phase concentrations of PCBs are elevated in the northern end of the lake and especially offshore of Chicago (Figure 1.5.1). The elevation in the northern end of the lake is related to the air station at Beaver Island. The site was discovered to be impacted by a local source of contamination and was not representative of that region of the lake.

Complete data are summarized in Table 1.5.2. Monthly mean composite concentrations ranged from 110 pg/m<sup>3</sup> outside the basin to 2600 pg/m<sup>3</sup> at IIT Chicago (McCarty *et al.*, 2004).

Historic information are sparse. Data sets vary in temporal and spatial scales. Data sets found include the period of 1976, 1979, and 1992-2002 (Murphy and Rzeszutko, 1977; Rice *et al.*, 1982; The Integrated Atmospheric Deposition Network, 2004). The Integrated Atmospheric Deposition Network (IADN) data for 2001 and 2002 were presented in a graphic by Boughton (2004) and attributed to the IADN Steering Committee, unpublished 2004. Vapor

**Table 1.5.1. Significant Dates in the History of PCBs in the Lake Michigan Basin**

<b>Date</b>	<b>Event</b>
1865	First PCB-like chemical discovered
1881	First PCBs synthesized
1914	Measurable amounts of PCBs found in bird feathers
1927	PCBs first manufactured at Anniston, Alabama
1935	PCBs manufactured at Anniston, Alabama and Sauget, Illinois
1948-1971	Outboard Marine Corporation at Waukegan, Illinois purchased eight million gallons of hydraulic fluid with PCBs
Mid-1950s to Mid-1960s	PCBs loaded to Kalamazoo River from deinking
1950s to 1980s	PCBs discharged to Manistique River and Harbor
1954	Appleton Paper Company began using PCBs as PCB-coated carbonless copy paper
1959-1971	PCBs used by Tecumseh Products Company as a hydraulic fluid was loaded to Sheboygan River
1959-1972	Outboard Marine Corporation at Waukegan, Illinois used hydraulic fluid with PCBs for die-casting
1969-1970	Paper company discharges of PCBs to Fox River peaked
1970	PCB production peaked at 85 million pounds and huge contamination noted at Sauget, Illinois plant
1971-1972	Appleton Paper Company and NCR Corporation phased out PCB use. Recycling of carbonless paper had occurred for several decades
1973	U.S. Food and Drug Administration (USFDA) establish 5 ppm PCB tolerance level in fish
1975	124,000 cans of salmon from Lake Michigan seized because of PCBs
1977	PCB production ends
1984	USFDA lowered PCB tolerance level in fish to 2 ppm
1985	Commercial fishing for carp and other valuable species outlawed on Green Bay
1991	End Sheboygan River PCB remediation of upper river
1991	U.S. Department of Health and Human Services label PCBs as possible carcinogen
1992	End Waukegan Harbor PCB remediation
1998	The eight Great Lakes states agreed on a "Great Lakes Protocol for Fish Consumption Advisories" that lowered the regional standard from the USFDA commercial standard of 2 ppm down to 0.05 ppm
1997-1998	Milwaukee River PCB remediation
2001	Manistique Harbor PCB remediation completed
2002	Possibly begin Grand Calumet River PCB remediation



**Figure 1.5.1. Median concentration of vapor phase PCBs in the atmosphere during 1994 and 1995 for all seasons of both years.**

**Table 1.5.2. Monthly Composite Concentrations of Vapor Phase Total PCBs Measured in Samples Collected Around Lake Michigan From April 1994 to October 1995**

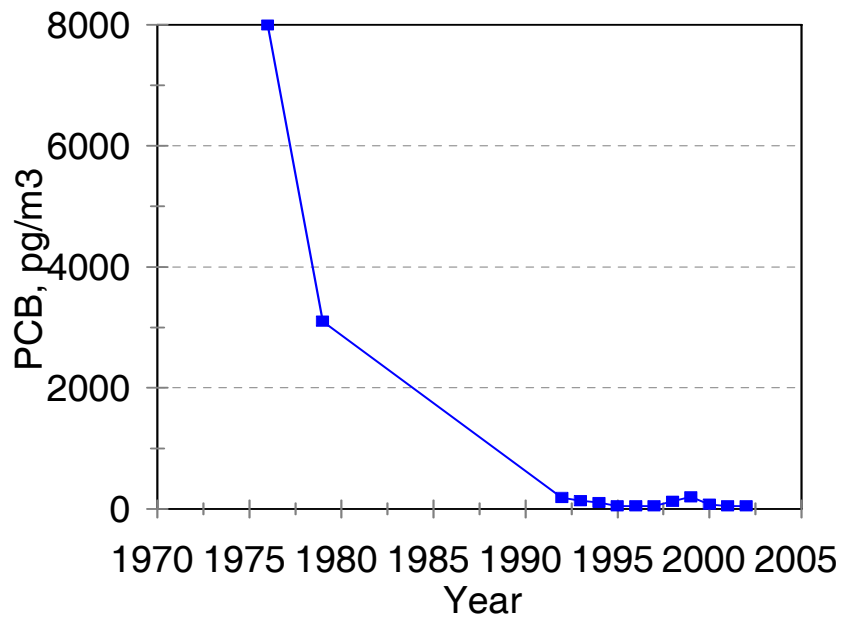
Sampling Station		N	Mean (pg/m <sup>3</sup> )	SD (pg/m <sup>3</sup> )
Shoreline Atmospheric Stations	Beaver Island	19	970	880
	Chiwaukee Prairie	19	320	230
	IIT Chicago	19	2600	1900
	Indiana Dunes	19	680	580
	Manitowoc	19	350	260
	Muskegon	18	490	410
	Sleeping Bear Dunes	15	380	550
	South Haven	19	400	360
Out-of-Basin Atmospheric Stations	Bondville	19	250	150
	Brule River	19	110	110
	Eagle Harbor	4	260	370
Over-Water Atmospheric Stations	Empire Michigan	4	170	77
	GB24M	4	940	1600
	1	5	990	1500
	5	6	670	590
	6	4	1200	1800
	110	3	810	1200
	18M	5	560	930
	23M	4	490	600
	27M	5	360	410
	280	4	480	570
	310	3	650	430
	380	1	290	NA
	40M	4	340	460
	41	2	21	6.4
	47M	5	410	630
	MB19M	1	280	NA
	11M	2	2200	3100

phase PCBs have decreased dramatically since the very first measurements in 1976 (Figure 1.5.2); however, the IADN data set vapor phase concentrations at Sleeping Bear Dunes does not show a definitive trend between 1992 and 2002 (Figure 1.5.3). For the period of 1992 through 2001, an examination of the temperature corrected PCB partial pressure IADN data revealed that partial pressures were declining with a half-life rate of  $8.3 \pm 1.5$  years (Buehler *et al.*, 2004). The 1994-1995 concentrations measured during the Lake Michigan Mass Balance Project (LMMBP) are considerably higher (21 to 2,600 pg/m<sup>3</sup>) than concentrations observed at Sleeping Bear Dunes (50 to 110 pg/m<sup>3</sup>).

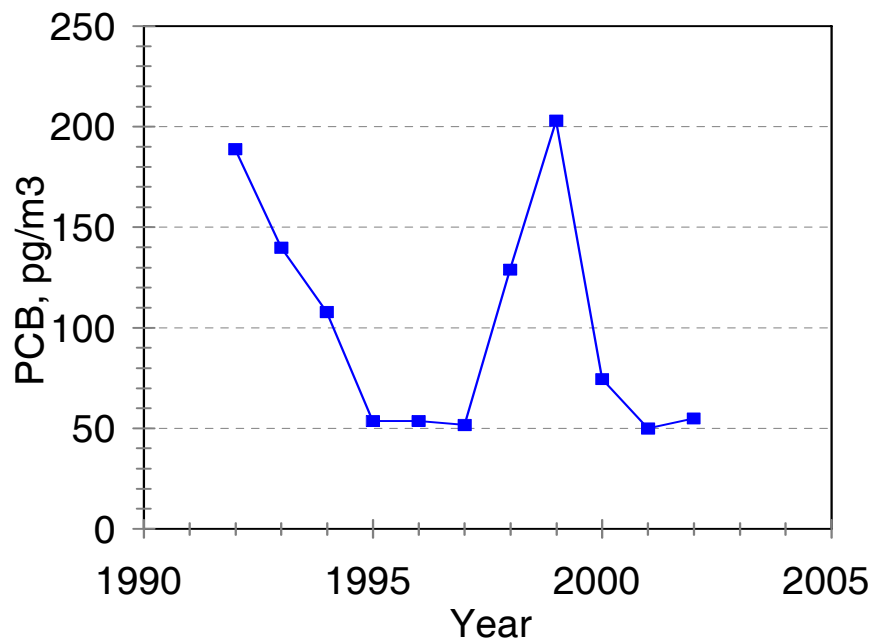
Thus it appears that Sleeping Bear Dunes does not represent the Lake Michigan basin. Concentrations observed at the Chicago IADN station were greater than 1,000 pg/m<sup>3</sup> for all the years (1993-2000) of observation (Buehler and Hites, 2002). Recently, an average concentration of 1,900 pg/m<sup>3</sup> PCBs was reported for June 2001 at Milwaukee, Wisconsin (Wethington and Hornbuckle, 2005).

### 1.5.2.2 Precipitation

Median precipitation concentrations of PCBs are elevated in the southern end of the lake and



**Figure 1.5.2. Time variation of vapor phase PCBs in Lake Michigan.**



**Figure 1.5.3. Time variation of vapor phase PCBs in Lake Michigan at Sleeping Bear Dunes based on IADN data.**

especially offshore of Chicago (Figure 1.5.4). Concentrations decline from south-to-north.

Complete data are summarized in Table 1.5.3. Monthly mean composite concentrations ranged from 290 pg/L outside the basin to 16,000 pg/L at IIT Chicago (McCarty *et al.*, 2004).

Historic concentrations of PCBs in precipitation were only available from IADN (2004). The time trend of the data are plotted in Figure 1.5.5. There is no apparent trend in the data. Again, the 1994-1995 basin results (360 to 16,000 ng/L) are higher than those reported by IADN for Sleeping Bear Dunes (955 to 2,849 ng/L). Sleeping Bear Dunes may under-represent the PCB concentration in precipitation. Chicago concentrations ranged between 3,500 and 8,600 ng/L for the 1996-2000 period of observation (IADN, 2004).

#### 1.5.2.3 Particulate

Median atmospheric particulate concentrations of PCBs are elevated in the southern end of the lake and especially offshore of Chicago (Figure 1.5.6). Concentrations decline from south-to-north and then increase slightly in the northern end of the lake. The elevation in the northern end of the lake is related to the air station at Beaver Island. The site was discovered to be impacted by a local source of contamination and was not representative of that region of the lake.

Complete data are summarized in Table 1.5.4. Monthly mean composite concentrations ranged from 0.37 pg/m<sup>3</sup> at an over-water station to 91 pg/m<sup>3</sup> at IIT Chicago (McCarty *et al.*, 2004).

Historic particulate concentrations of PCBs were only available from IADN (2004). The time trend of the data are plotted in Figure 1.5.7. Again, the 1994-1995 basin results (0.37 to 91 pg/m<sup>3</sup>) are higher than those reported by IADN at Sleeping Bear Dunes (7.8 to 9.2 pg/m<sup>3</sup>). Sleeping Bear Dunes under-represents the PCB concentration in particulates. Samples collected in June 2001 at Milwaukee averaged 50 pg/m<sup>3</sup> (Wethington and Hornbuckle, 2005).

#### 1.5.2.4 Dry Deposition

Some measurements were made of PCB concentrations in dry deposition (Table 1.5.5). Highest mean concentration (315,000 ng/m<sup>2</sup>) occurred at South Haven and the lowest mean concentration (1,830 ng/m<sup>2</sup>) occurred at the Chicago SWFP crib intake (McCarty *et al.*, 2004). Thus the mean range was very large and fluxes could be high. However, the limited number of data points and high standard deviations precluded any further interpretation of the data.

### 1.5.3 Lake Water

Water concentrations measured included dissolved, particulate, and total PCBs. Results are plotted for the 1994 through 1995 stations. Only stations representative of all annual seasons were included in the figures.

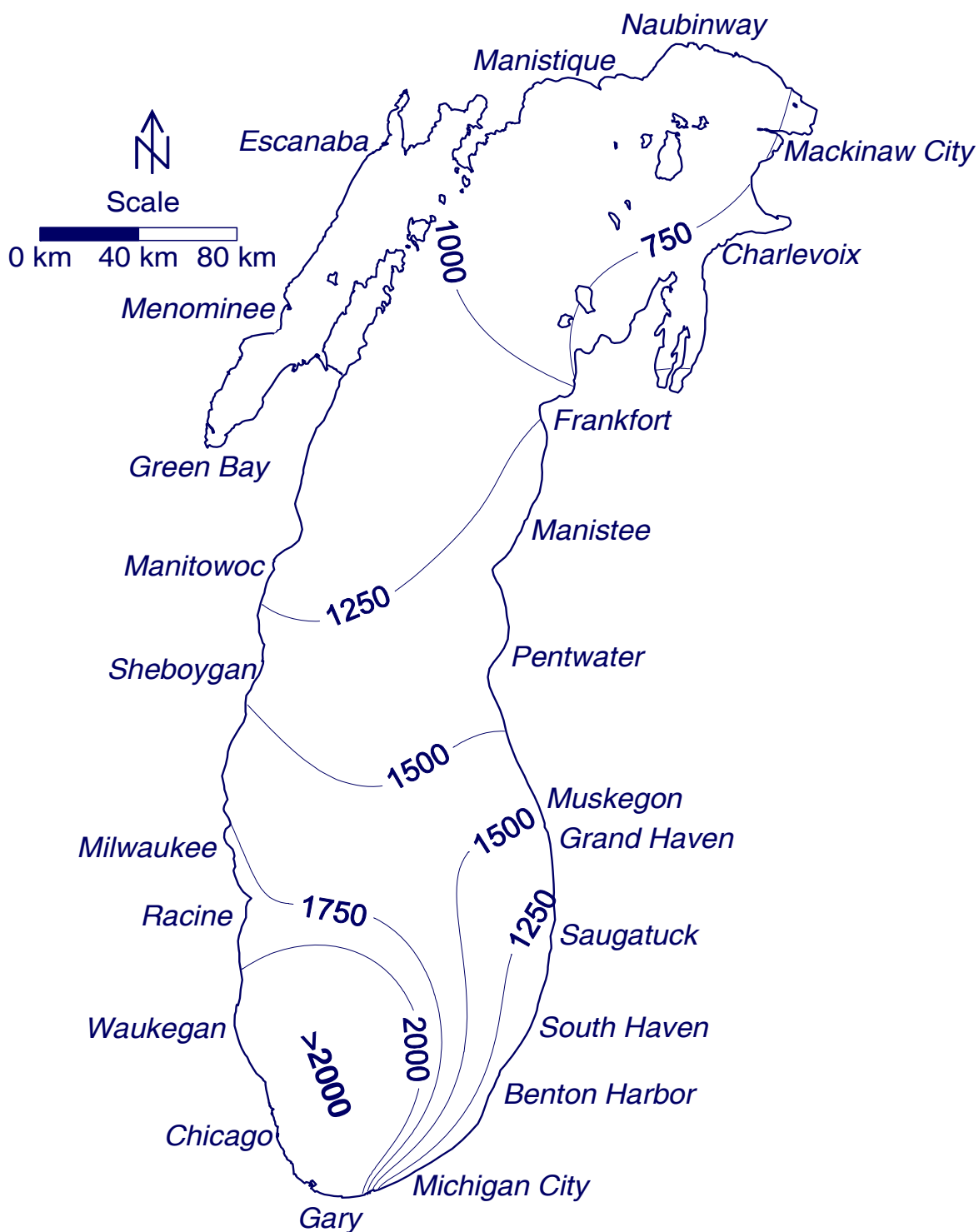
#### 1.5.3.1 Total PCBs

Total PCB concentrations in lake water were elevated in southern and central Lake Michigan (Figure 1.5.8). Of note were high concentrations offshore of Milwaukee and along the eastern shoreline from South Haven to Manistee. Highest concentrations were found along the shoreline of the lake. Concentrations are summarized in Table 1.5.6 and averaged 0.25 ppb in 1994 and 0.27 ppb in 1995 (McCarty *et al.*, 2004).

Historic data were available for the period of 1976 through 1994 (Chambers and Eadie, 1980; Rice *et al.*, 1982; Anderson *et al.*, 1999; Offenberger and Baker, 2000; Bicksler, 1996; Murphy and Rzeszutko, 1977; Swackhamer and Armstrong, 1987; Filkins *et al.*, 1983; Lefkovitz, 1987; Pearson *et al.*, 1996). Since 1976, concentrations have dramatically decreased (Figure 1.5.9). Expanding the scale and looking only at the 1986 and later data, concentrations decrease from 1986 to 1993; however, they appear constant since 1993 (Figure 1.5.10).

#### 1.5.3.2 Dissolved PCBs

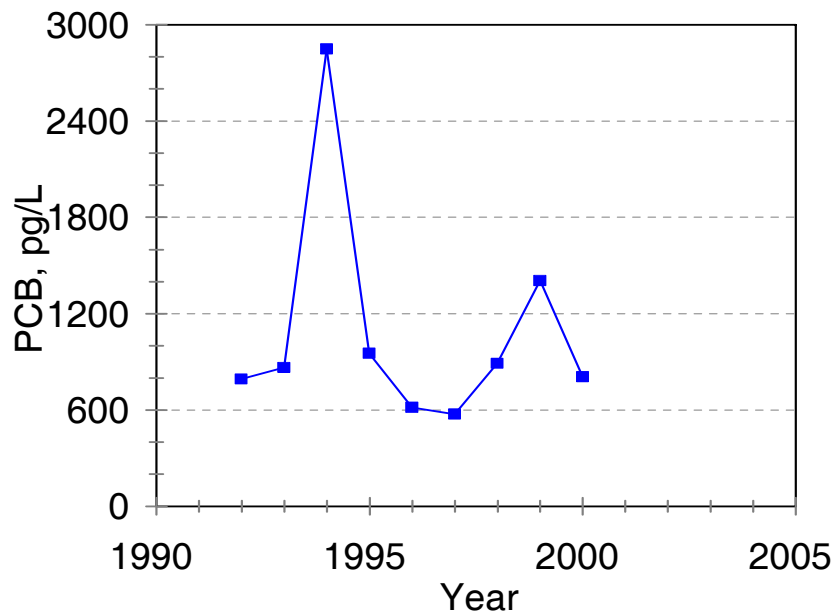
Dissolved PCBs had a pattern similar to that of total PCBs. Concentrations were highest in the southern basin of the lake with special note of the Milwaukee, Michigan City, Saugatuck, and Grand Haven



**Figure 1.5.4. Median concentration of wet (precipitation) PCBs in the atmosphere during 1994 and 1995 for all seasons of both years.**

**Table 1.5.3. Monthly Composite Concentrations of Total PCBs Measured in Precipitation Samples Collected Around Lake Michigan From April 1994 to October 1995**

Sampling Station		N	Mean (pg/L)	SD (pg/L)
Shoreline Atmospheric Stations	Beaver Island	20	1900	2800
	Chiwaukee Prairie	20	1800	1200
	IIT Chicago	17	16000	28000
	Indiana Dunes	21	1500	1500
	Manitowoc	20	2600	4200
	Muskegon	20	2600	4000
	Sleeping Bear Dunes	16	1300	880
	South Haven	21	3800	10000
Out-of-Basin Atmospheric Stations	Bondville	21	1700	1100
	Brule River	19	1700	2900
	Eagle Harbor	4	290	300
Over-Water Atmospheric Stations	Empire Michigan	4	2000	2000
	GB17	1	2300	
	GB24M	1	680	
	1	1	750	
	5	1	1500	
	23M	1	360	
	380	1	510	



**Figure 1.5.5. Time variation of precipitation PCBs in Lake Michigan at Sleeping Bear Dunes based on IADN data.**



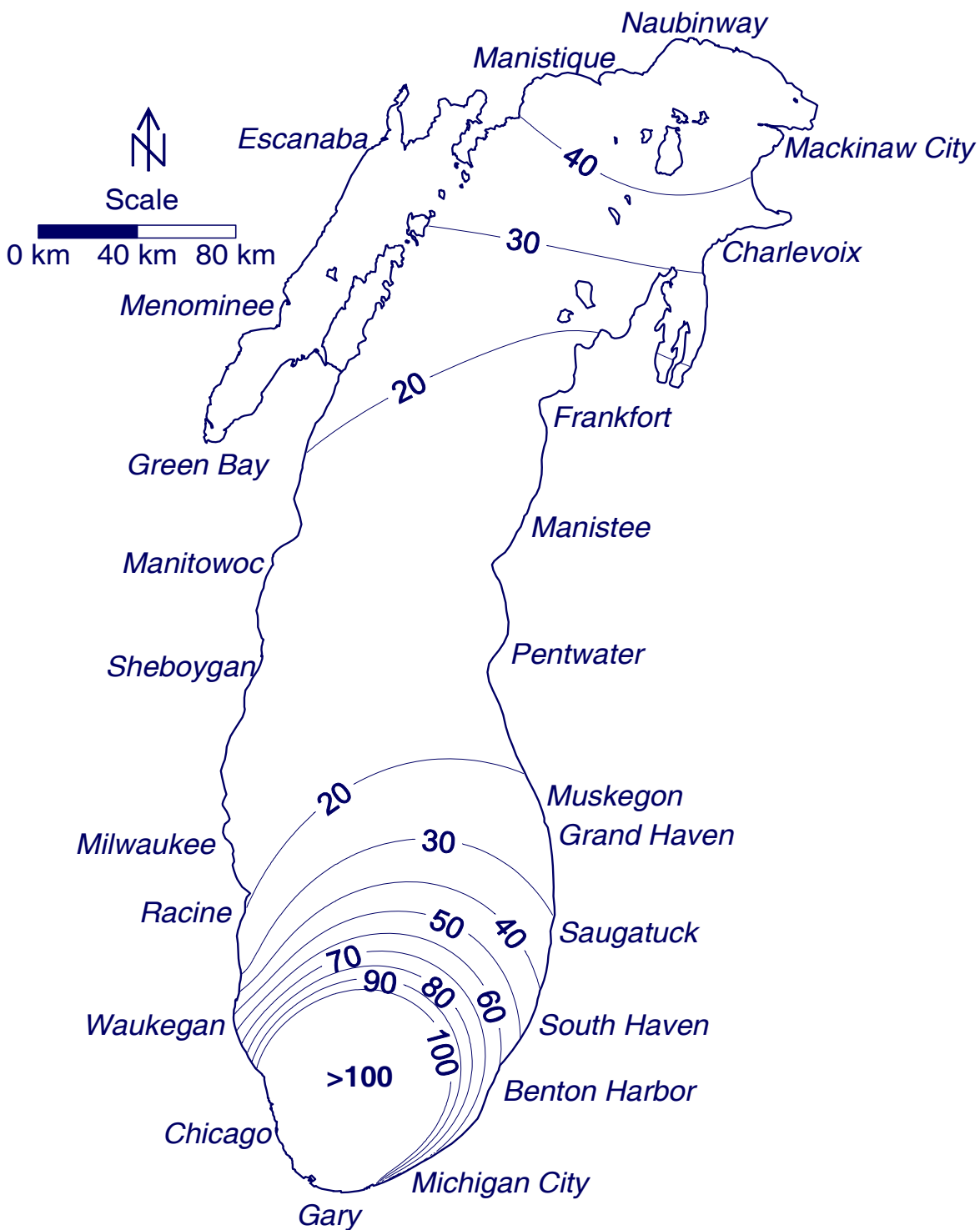
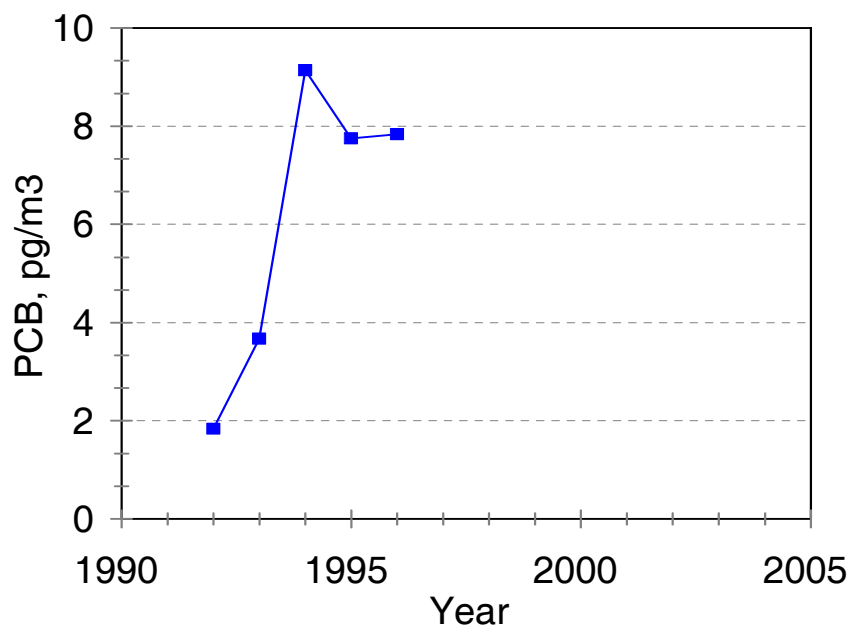


Figure 1.5.6. Median concentration of particulate PCBs in the atmosphere during 1994 and 1995 for all seasons of both years.

**Table 1.5.4. Monthly Composite Concentrations of Particulate Phase Total PCBs Measured in Samples Collected Around Lake Michigan From April 1994 to October 1995**

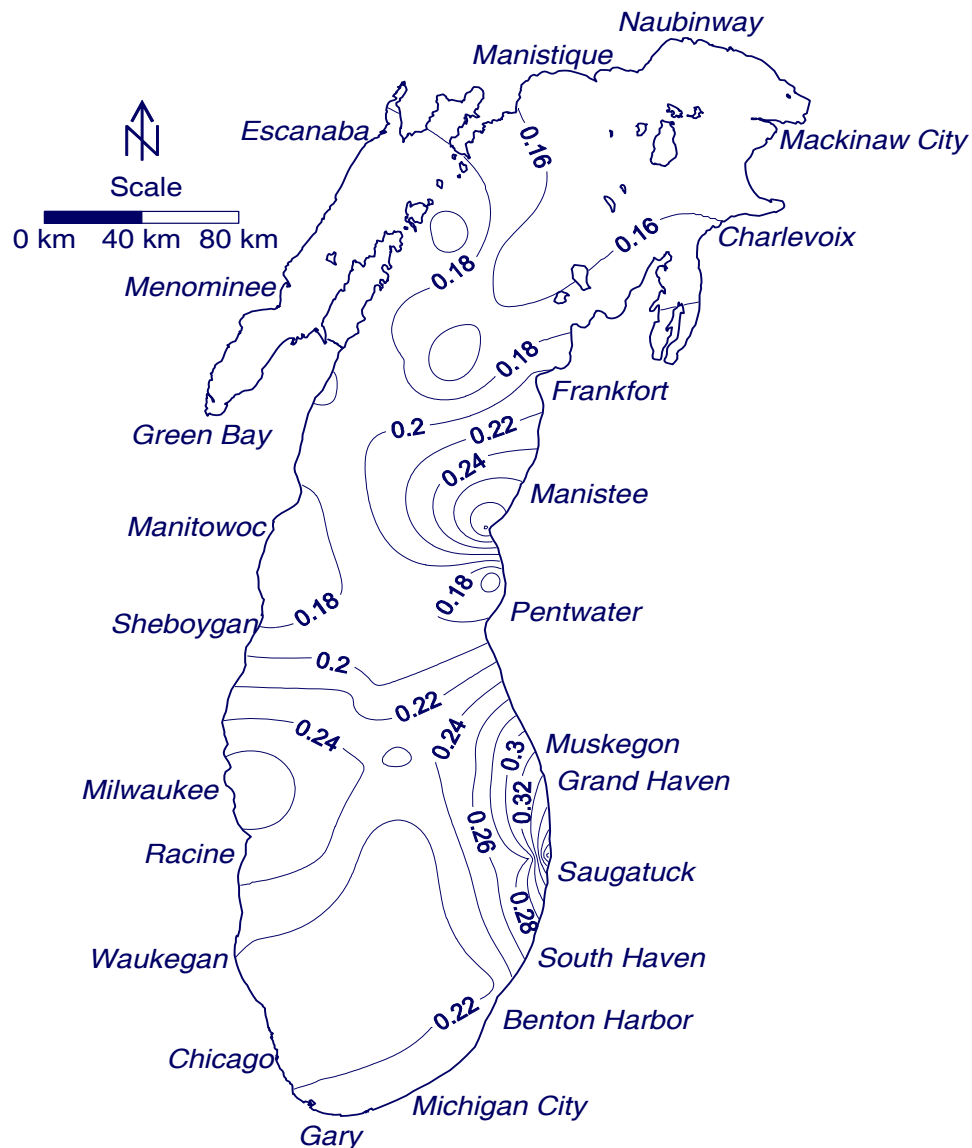
Sampling Station		N	Mean (pg/m <sup>3</sup> )	SD (pg/m <sup>3</sup> )
Shoreline Atmospheric Stations	Beaver Island	18	52	29
	Chiwaukee Prairie	19	22	6.1
	IIT Chicago	19	91	48
	Indiana Dunes	19	33	12
	Manitowoc	19	26	22
	Muskegon	16	24	12
	Sleeping Bear Dunes	15	18	21
	South Haven	18	23	12
Out-of-Basin Atmospheric Stations	Bondville	19	25	14
	Brule River	18	21	14
	Eagle Harbor	4	14	4.7
Over-Water Atmospheric Stations	Spatial Composites	18	19	21
	Empire Michigan	4	14	4.0
	GB24M	2	3.9	5.2
	1	1	2.6	
	5	3	17	27
	6	1	0.37	



**Figure 1.5.7. Time variation of atmospheric particulate PCBs in Lake Michigan at Sleeping Bear Dunes based on IADN data.**

**Table 1.5.5. Monthly Composite Concentrations of PCBs Measured in Dry Deposition**

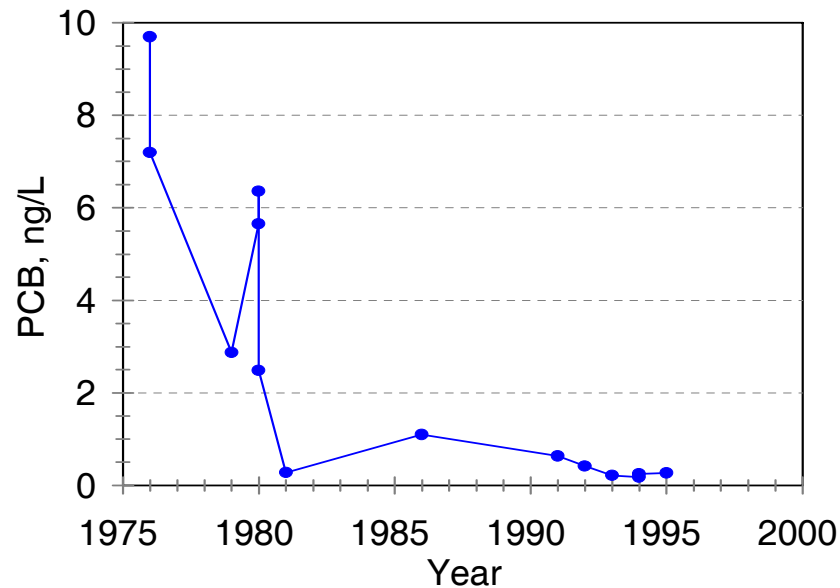
Sampling Station	N	Mean (ng/m <sup>2</sup> )	SD (ng/m <sup>2</sup> )
Chicago SWFP Crib Intake	9	1830	1710
Harrison Crib	1	5400	
IIT Chicago	13	7060	6480
Sleeping Bear Dunes	8	6120	7940
South Haven	11	315,000	1,020,000



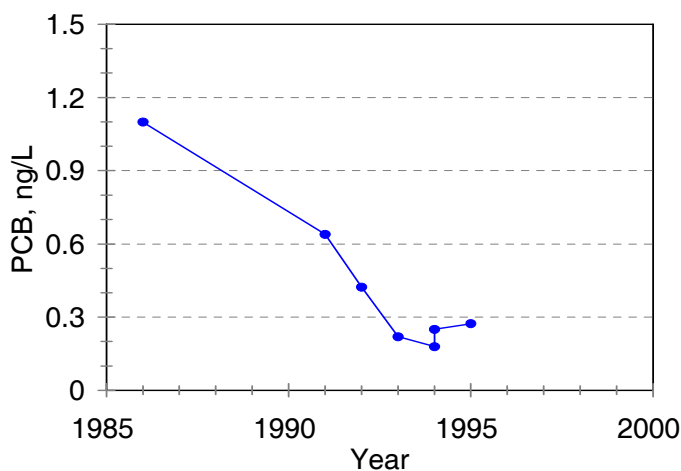
**Figure 1.5.8. Distribution of total PCBs (ng/L) in 1994-1995 Lake Michigan water.**

**Table 1.5.6. Concentrations of PCBs in 1994-1995 Lake Michigan Water (ng/L)**

Year	Descriptive Statistics	Dissolved PCBs	Particulate PCBs	Total PCBs
1994	Mean	0.17	0.079	0.25
1994	Standard Deviation	0.11	0.088	0.16
1994	Number of Samples	181	181	181
1995	Mean	0.21	0.066	0.27
1995	Standard Deviation	0.16	0.060	0.19
1995	Number of Samples	142	142	142



**Figure 1.5.9. Time variation of total PCBs in Lake Michigan water. Historic data from Chambers and Eadie (1980), Rice *et al.* (1982), Anderson *et al.* (1999), Offenbergh and Baker (2000), Bicksler (1996), Murphy and Rzeszutko (1977), Swackhamer and Armstrong (1987), Filkins *et al.* (1983), Lefkovitz (1987), and Pearson *et al.* (1996).**



**Figure 1.5.10. Time variation of total PCBs in Lake Michigan water since 1986. Historic data from Anderson *et al.* (1999), Offenberg and Baker (2000), Bicksler (1996), Lefkovitz (1987), and Pearson *et al.* (1996).**

locations (Figure 1.5.11). Green Bay appears as a source of dissolved PCBs to the lake. For the lake as a whole, concentrations averaged 0.17 ppb with a standard deviation of 0.11 ppb in 1994 and 0.21 ppb with a standard deviation of 0.16 ppb in 1995 (Table 1.5.6) (McCarty *et al.*, 2004).

During the summer thermal stratification, dissolved PCB concentrations in the hypolimnion are notably high offshore of the region bounded by Racine and Michigan City and centered on Waukegan (Figure 1.5.12). This region appears to continue to be impacted by the historical contamination at Waukegan (Swackhamer and Armstrong, 1988).

Dissolved PCB data were found for the period of 1991 through 1994 (Anderson *et al.*, 1999; Offenberg and Baker 2000; Pearson *et al.*, 1996). What few data are available illustrate a downward trend in concentration (Figure 1.5.13). This is similar to the trend observed for total PCBs.

### 1.5.3.3 Particulate PCBs

Particulate PCB concentrations were highest along the shoreline, notably at Saugatuck and especially at Milwaukee (Figure 1.5.14). Concentrations averaged 0.079 ppb with a standard deviation of 0.088 ppb in 1994 and 0.066 ppb with a standard deviation of 0.060 ppb in 1995 (Table 1.5.6) (McCarty *et al.*, 2004).

Particulate PCB data were derived from the difference between total and dissolved concentrations for the period of 1991 through 1994 from the data of Anderson *et al.* (1999), Offenberg and Baker (2000), and Pearson *et al.* (1996). The variation of these and the project data is one of a decreasing trend (Figure 1.5.15).

## 1.5.4 Tributaries

Tributary water concentrations measured included dissolved and particulate forms. Mean particulate concentrations were higher than mean dissolved concentrations in the Fox, Grand Calumet, Grand, Kalamazoo, Pere Marquette, Sheboygan, and St. Joseph Rivers (Table 1.5.7) (McCarty *et al.*, 2004). Concentrations of dissolved PCBs were highest in the Grand Calumet River and lowest in the Pere Marquette River. Concentrations of particulate PCBs were highest in the Sheboygan River and lowest in the Muskegon River. Loads of total PCBs to Lake Michigan were highest for the Fox River and lowest for the Manistique River (Figure 1.5.16).

One historic data set for PCBs in Lake Michigan tributaries was found (Marti and Armstrong, 1990). These data permitted comparison of the Fox, Grand Calumet, Grand, Kalamazoo, Manistique, Menominee, Milwaukee, Muskegon, Pere Marquette, Sheboygan, and St. Joseph Rivers for dissolved and particulate PCB concentrations. Between 1980 and 1995, dissolved PCB concentrations decreased at all

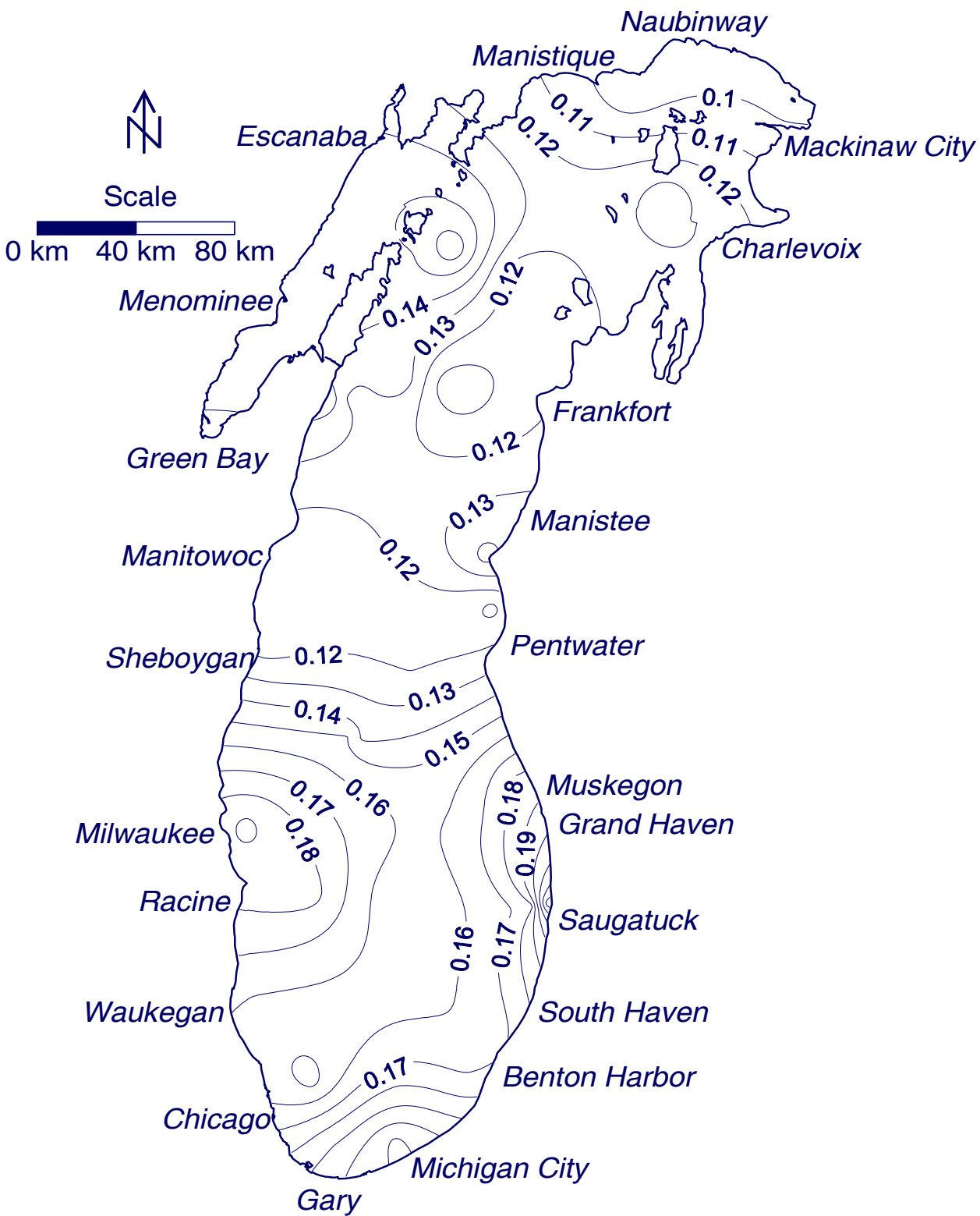
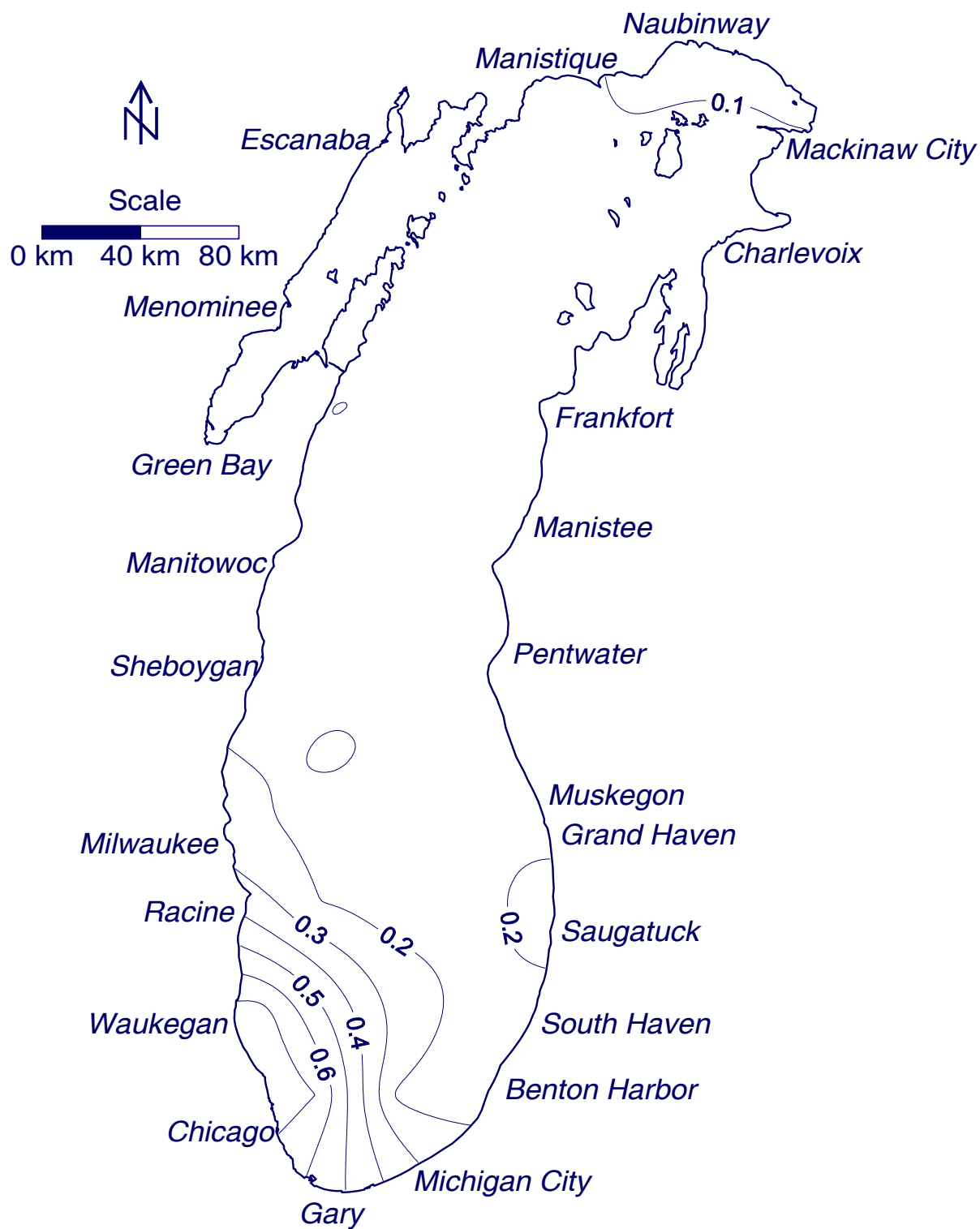
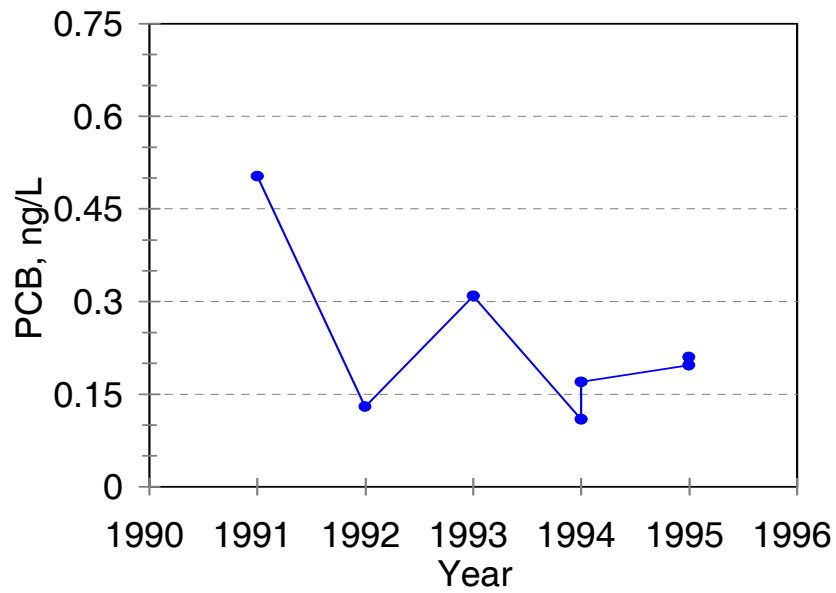


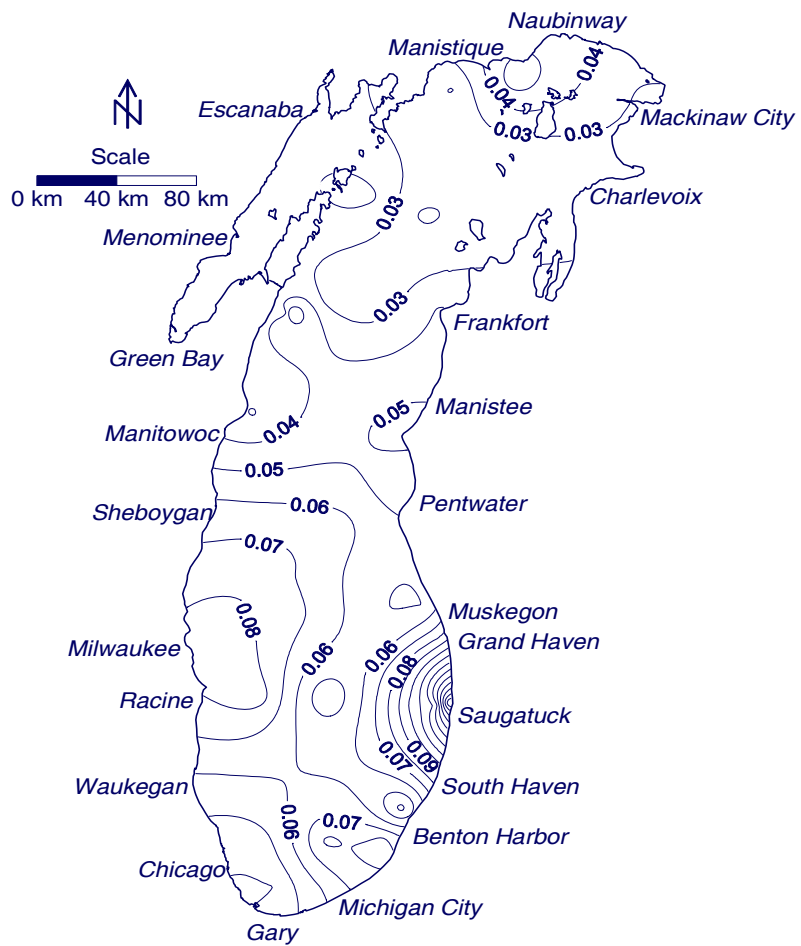
Figure 1.5.11. Distribution of dissolved PCBs (ng/L) in 1994-1995 Lake Michigan water.



**Figure 1.5.12. Distribution of dissolved PCBs (ng/L) in 1994-1995 summer hypolimnetic Lake Michigan water.**

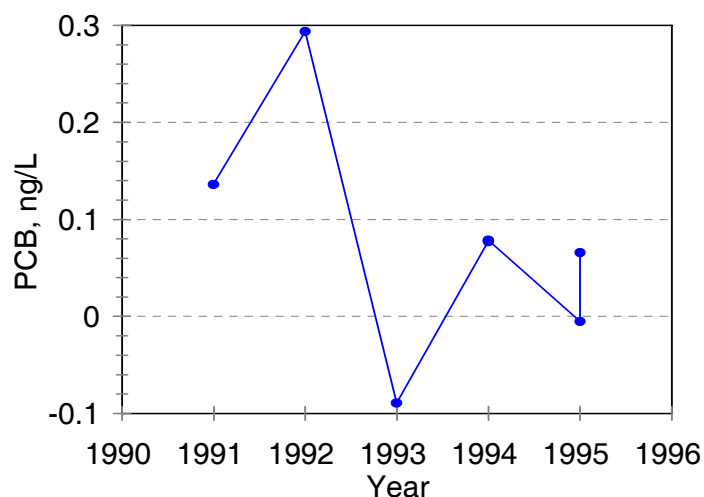


**Figure 1.5.13. Time variation of dissolved PCBs in Lake Michigan water.**



**Figure 1.5.14. Distribution of particulate PCBs (ng/L) in 1994-1995 Lake Michigan water.**

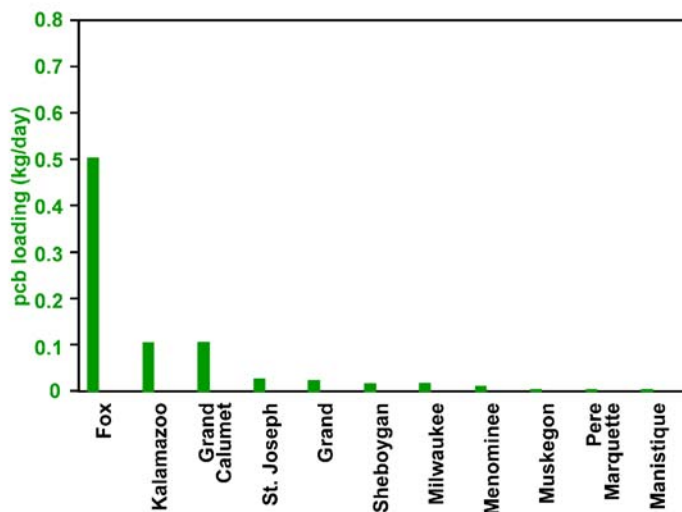




**Figure 1.5.15. Time variation of particulate PCBs in Lake Michigan water.**

**Table 1.5.7. Concentrations of PCBs Measured in Tributaries**

Fraction	Tributary	N	Mean (ng/L)	SD (ng/L)
Dissolved	Fox River	39	14	7.6
	Grand Calumet	15	35	6.5
	Grand River	47	0.76	0.35
	Kalamazoo	38	6.9	2.1
	Manistique	28	0.76	0.39
	Menominee	24	1.4	2.1
	Milwaukee	38	13	4.0
	Muskegon	28	0.58	0.40
	Pere Marquette	28	0.43	0.19
	Sheboygan	36	26	8.3
	St. Joseph	33	1.0	0.53
Particulate	Fox River	39	39	25
	Grand Calumet	15	41	22
	Grand River	47	1.6	0.63
	Kalamazoo	38	16	9.6
	Manistique	28	0.41	0.37
	Menominee	24	0.52	0.27
	Milwaukee	38	11	6.2
	Muskegon	28	0.25	0.14
	Pere Marquette	28	0.47	0.32
	Sheboygan	36	55	31
	St. Joseph	33	1.9	0.98



**Figure 1.5.16. Relative loads of PCBs to Lake Michigan from tributaries.**

but one of the tributaries that could be compared (Table 1.5.8). Particulate PCB concentrations declined at all locations between 1980 and 1995 (Table 1.5.8).

### 1.5.5 Sediment

PCB concentrations in Lake Michigan surficial (0.5 to 1.5 cm in thickness) sediments ranged between 0.066 and 220 ng/g for samples collected between 1994 and 1996 (Table 1.5.9). This is similar to the range reported by Swackhamer and Armstrong (1988) for samples collected between 1978 and 1980. The mean concentration in 1994-1996 was 47 ng/g. This is within the range of means reported by Swackhamer and Armstrong (1988) for depositional (81 ng/g), transitional (26 ng/g), and non-depositional (7.2 ng/g) regions of the lake as defined by Cahill (1981). All of these results are considerably higher than those reported by Frank *et al.* (1981) for 1975 (Table 1.5.9). Results of the 1975 samples represented samples that had been freeze-dried. Freeze-drying can result in the loss of volatile contaminants from the sediment samples. The spatial variation of PCBs in the main lake surficial sediments in 1994-1996 is consistent with that reported by Frank *et al.* (1981) and Swackhamer and Armstrong (1988). Concentrations are elevated in southeastern Lake Michigan, offshore of Sheboygan,

and offshore of Frankfort (Figure 1.5.17). Of these three areas, PCB concentrations are highest in southeastern Lake Michigan.

Currently, LMMBP PCB results are available for six sediment cores (Figure 1.5.18) (Eadie and Van Hoof, personal communication). All of these cores illustrate the decline in PCB concentrations in recent times. The cores are of varying resoluteness due to the thickness of the surface mixed layer which results in varying particle residence times in the mixed layer (Table 1.5.10). Historic records indicate the first use of PCBs in the basin began no earlier than 1948. PCBs occurring in cores prior to 1948 represent vapor phase PCBs transported to the basin, the failure of sealed sources within the basin, or physical processes within the lake associated with the surface mixed layer of the cores. The surface mixed layer is a surficial zone of the sediment that is consistently mixed by physical or biotic processes. This mixing homogenizes the sediment to a given depth referred to as the mixed layer. The residence time of a particle and its associated PCBs varies from core to core (Robbins *et al.*, 1999). For the six cores this residence time varies from 0.0 to 31.5 years. Thus some cores are highly resolved (LM-94-15) and some are poorly resolved (LM-95-58). This results in differences for the apparent time of appearance of PCBs in the cores.

**Table 1.5.8. Comparison of PCB Concentrations in Samples Collected From Tributaries in 1994-1995 With Those in Samples Collected From Tributaries in 1980-1983 (Marti and Armstrong, 1990)**

Tributary	1980-1983 Dissolved Mean Concentration (ng/L)	1994-1995 Dissolved Mean Concentration (ng/L)	1980-1983 Particulate Mean Concentration (ng/L)	1994-1995 Particulate Mean Concentration (ng/L)
Fox River	17	14	81	39
Grand Calumet	24	35	220	41
Grand River	16	0.76	41	1.6
Kalamazoo	9	6.9	31	16
Manistique	6	0.76	18	0.41
Menominee	6	1.4	9	0.52
Milwaukee	28	13	69	11
Muskegon	4	0.58	5	0.25
Pere Marquette	4	0.43	10	0.47
Sheboygan	34	26	69	55
St. Joseph	7	1.0	7	1.9

**Table 1.5.9. Concentrations of Total PCBs in Lake Michigan Surficial Sediment (ng/g)**

Year Collected	Number of Samples	Mean	Standard Deviation	Minimum	Maximum	Median	Source
1994- 1996	113	47	48	0.066	220	29	LMMBP
1975	179	9.7	15.7				Frank <i>et al.</i> , 1981
1978- 1980	60	7.2-81		1.0	201		Swackhamer and Armstrong, 1988

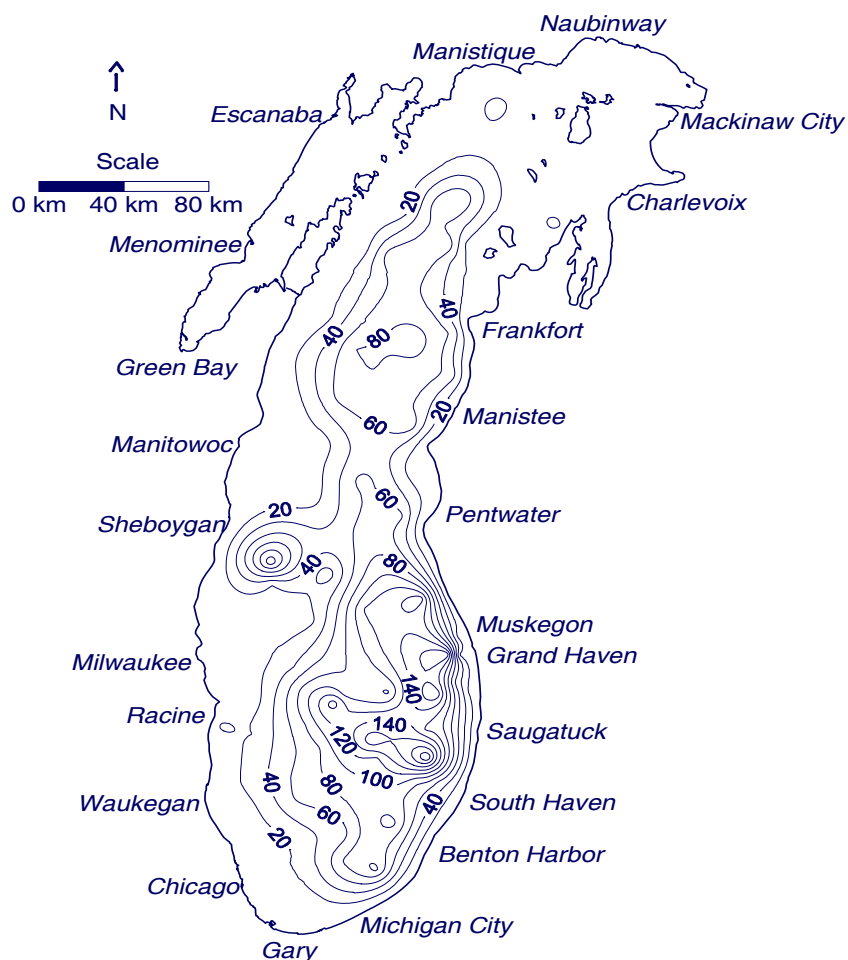


Figure 1.5.17. Total PCBs in 1994-1995 Lake Michigan surficial sediments (ng/g).

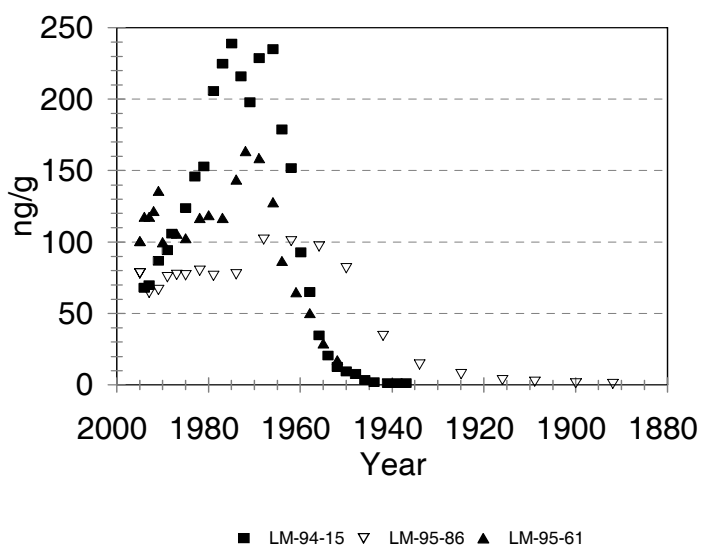


Figure 1.5.18. Vertical variation of PCBs in dated sediment cores collected for the LMMBP.

**Table 1.5.10. Physical Parameters Associated With LMMBP Cores (Robbins *et al.*, 1999; Eadie and Van Hoof, Personal Communication)**

Station Number	Sedimentation Rate g/cm <sup>2</sup> /year	Mixed Layer Residence Time, Year	Year of Peak PCB Concentration	Year of PCB Onset Above Background
LM-94-15	0.2235	0.0	1965, 1972	1943
LM-95-58	0.0357	31.5		
LM-95-61	0.1064	7.8	1969	1916
LM-95-86	0.0312	14.9	1968	1917
LM-95-103	0.0266	23.1	~1953	Prior to 1916
LM-95-108	0.0511	12.5	~1961	1932

Historic cores include those reported by Swackhamer and Armstrong (1988), Hermanson *et al.* (1991), Golden *et al.* (1993), and Schneider *et al.* (2001) (Figures 1.5.19 to 1.5.22). The core reported by Swackhamer and Armstrong (1988) was collected in 1980 (Figure 1.5.19). It failed to capture any decline in PCBs attributable to the ceasing of the manufacture of PCBs in 1977. For cores collected in 1984, a decline in PCBs was documented in four of the five cores (Figure 1.5.20). For these cores, the apparent peak of PCBs occurred after 1965. Cores collected in 1991 and 1992 had a peak PCB concentration between the early 1960s and early 1980s (Figure 1.5.21), and the core collected in 1998 had a peak concentration in the mid-1970s (Figure 1.5.22). Peak concentrations in all these cores are consistent with the LMMBP cores which had a peak concentration between the early 1960s and early 1970s (Figure 1.5.18).

### 1.5.6 Biota

Various biota were analyzed for PCBs. These include phytoplankton, zooplankton, *Diporeia*, *Mysis*, alewife, bloater, deepwater sculpin, smelt, slimy sculpin, coho, and lake trout (Table 1.5.11). Mean concentrations ranged from 49 ng/g in phytoplankton to 3,000 ng/g in lake trout. For alewife and bloater, the fish were divided into two size classes based on length. For both of these, PCB concentrations were higher in the larger fish. Concentrations of PCBs in members of the lake trout food web increase with trophic level, with concentrations lowest in the plankton, higher in benthos, and highest in the forage

fish, illustrating biomagnification of PCBs (Figure 1.5.23). For lake trout, PCB concentrations increased in a predictable way with fish age until age 10 (Figure 1.5.24). All PCB concentrations in lake trout exceed those of their prey. For unknown reasons, age 11 fish and older have PCB concentrations that vary in no predictable way with increasing age.

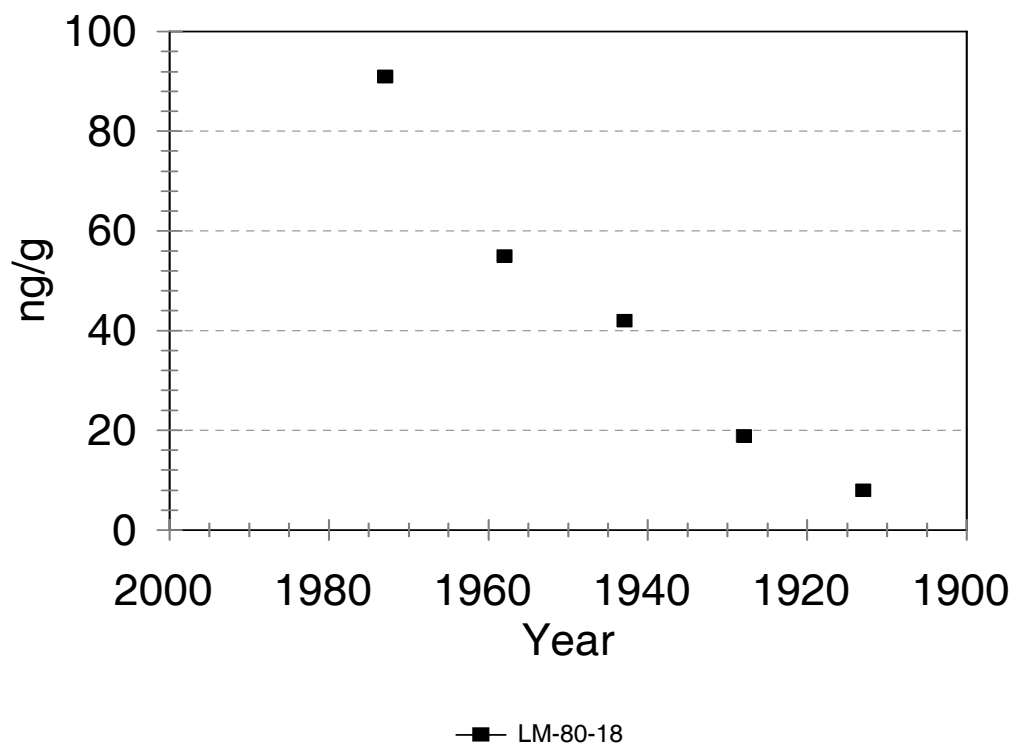
PCB concentrations in lake trout have been declining since 1975 (Figure 1.5.25). Similarly, concentrations of PCBs have declined in bloater since 1974 (Figure 1.5.26). These appear to be responding to the phase-out of PCB use in the basin which occurred at most locations by the early 1970s (Table 1.5.1).

### 1.5.7 Summary

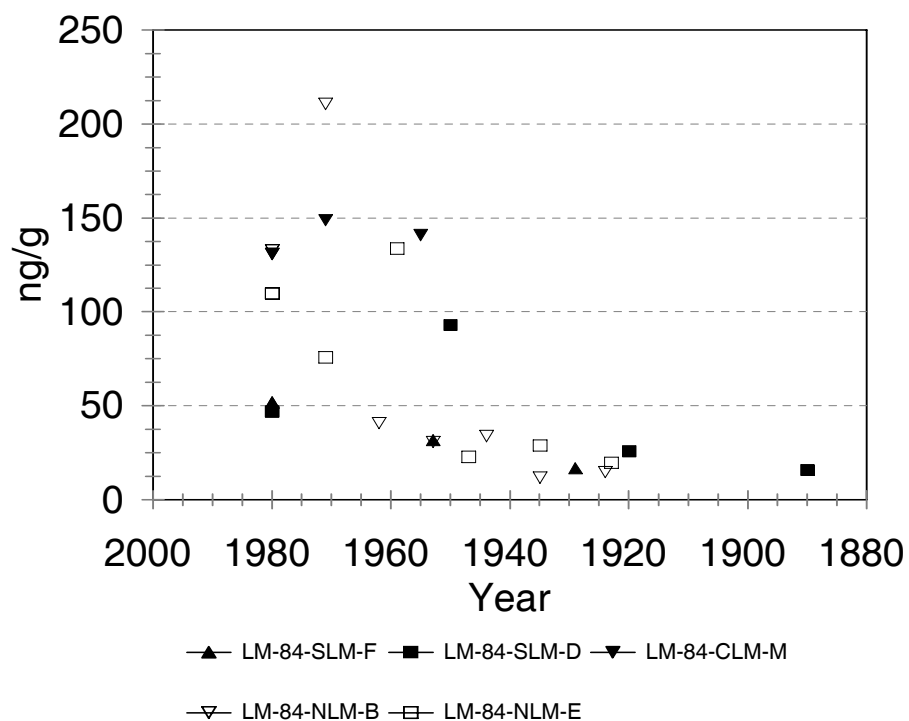
Concentrations of PCBs have declined in Lake Michigan since the phase-out of use by industries within the basin. Concentrations are highest in southern Lake Michigan for most media. For air and water media, concentrations are highest near shoreline sources.

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**Figure 1.5.19. Vertical variation of PCBs in dated sediment cores reported by Swackhamer and Armstrong (1988).**



**Figure 1.5.20. Vertical variation of PCBs in dated sediment cores reported by Hermanson *et al.* (1991).**

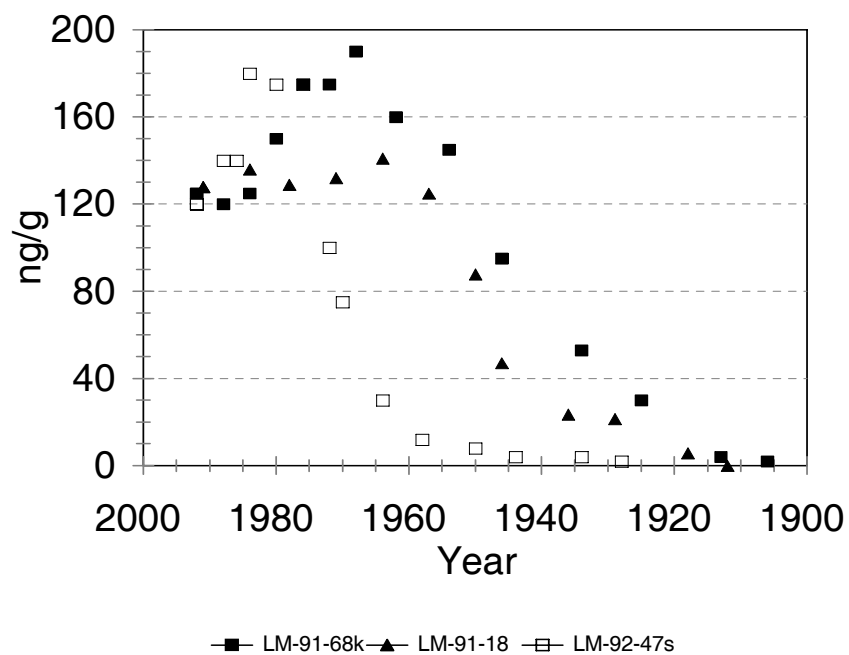


Figure 1.5.21. Vertical variation of PCBs in dated sediment cores reported by Golden *et al.* (1993).

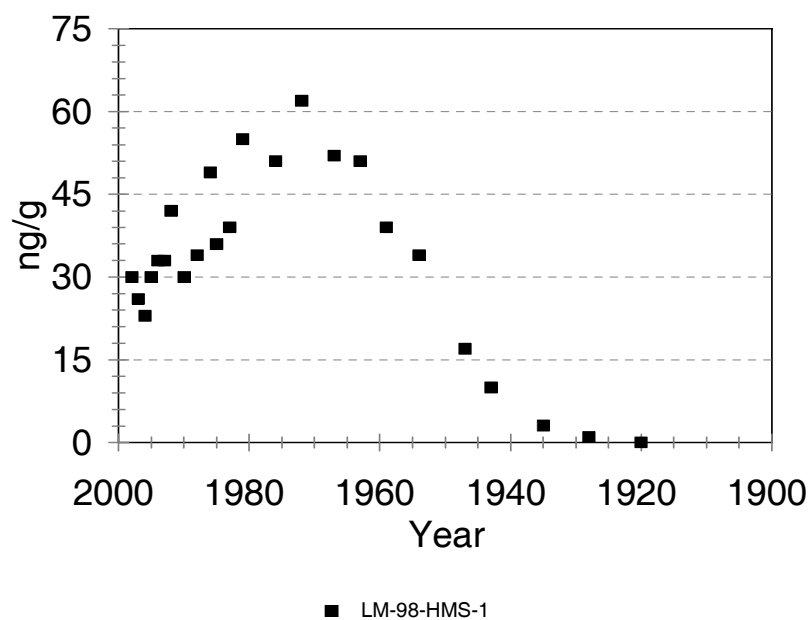
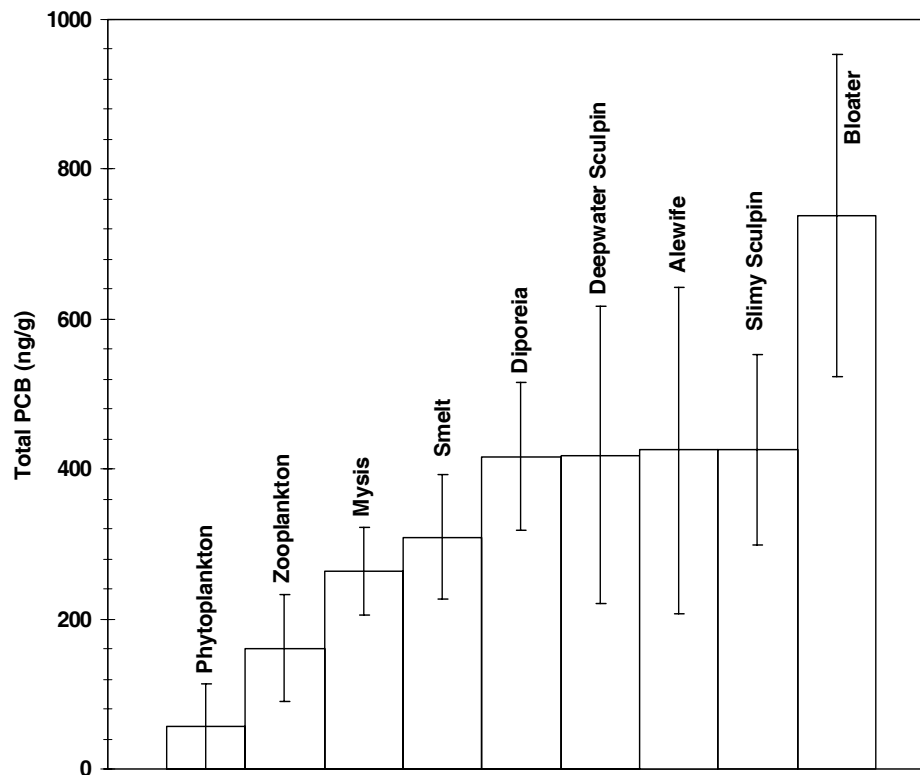


Figure 1.5.22. Vertical variation of PCBs in dated sediment cores reported by Schneider *et al.* (2001).

**Table 1.5.11. Mean Concentrations of PCBs Measured in the 1994-1995 Lake Michigan Food Web (McCarty *et al.* 2004)**

Sample Type	N	Mean (ng/g)	Standard Deviation (ng/g)
Phytoplankton	71	49	38
Zooplankton	70	170	74
<i>Mysis</i>	53	250	61
<i>Diporeia</i>	39	420	100
Smelt	73	310	83
Slimy Sculpin	69	430	130
Deepwater Sculpin	74	420	200
Alewife < 120 mm	60	250	150
Alewife > 120 mm	70	580	140
Bloater < 160 mm	70	650	180
Bloater > 160 mm	67	830	210
Coho - Hatchery	5	120	27
Coho - Yearling	8	200	90
Coho - Adult	54	810	520
Lake Trout (All Age Classes)	246	3000	2300



**Figure 1.5.23. PCB concentrations in various members of the lake trout food web during the LMMBP.**



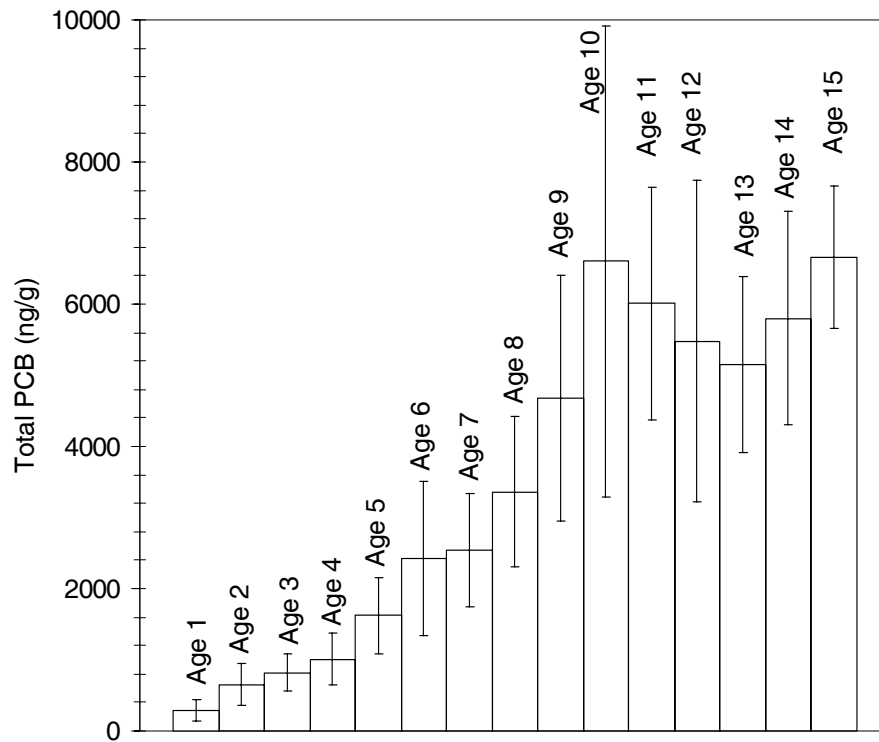


Figure 1.5.24. PCB concentrations in various age classes of lake trout during the LMMBP.

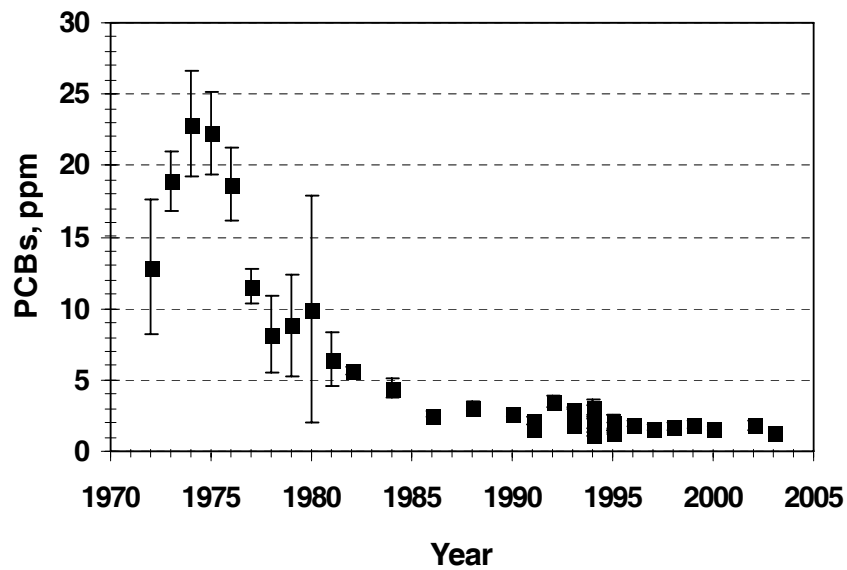
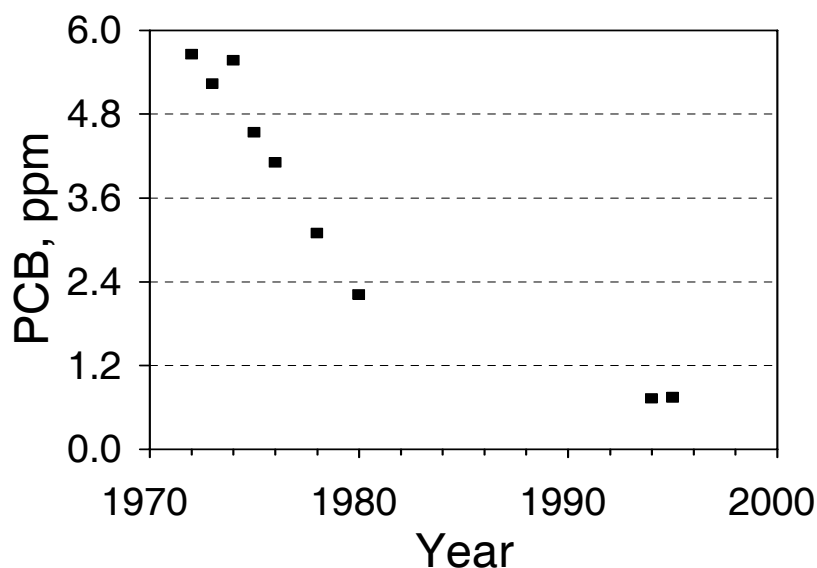


Figure 1.5.25. Time variation of PCB concentration in five to six year-old lake trout from Lake Michigan.



**Figure 1.5.26. Time variation of PCB concentrations in bloater from Lake Michigan.**

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